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(54) **GROUND-BASED BEAMFORMING FOR
SATELLITE COMMUNICATIONS SYSTEMS**

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(57) **ABSTRACT**

(52) **U.S. Cl.** **455/13.2**; 455/12.1; 455/427;
370/316; 342/174; 342/373

(58) **Field of Classification Search** 455/427,
455/430, 12.1, 13.1, 13.2, 13.3, 67.11, 67.14,
455/67.16, 69; 370/316; 342/174, 354, 373
See application file for complete search history.

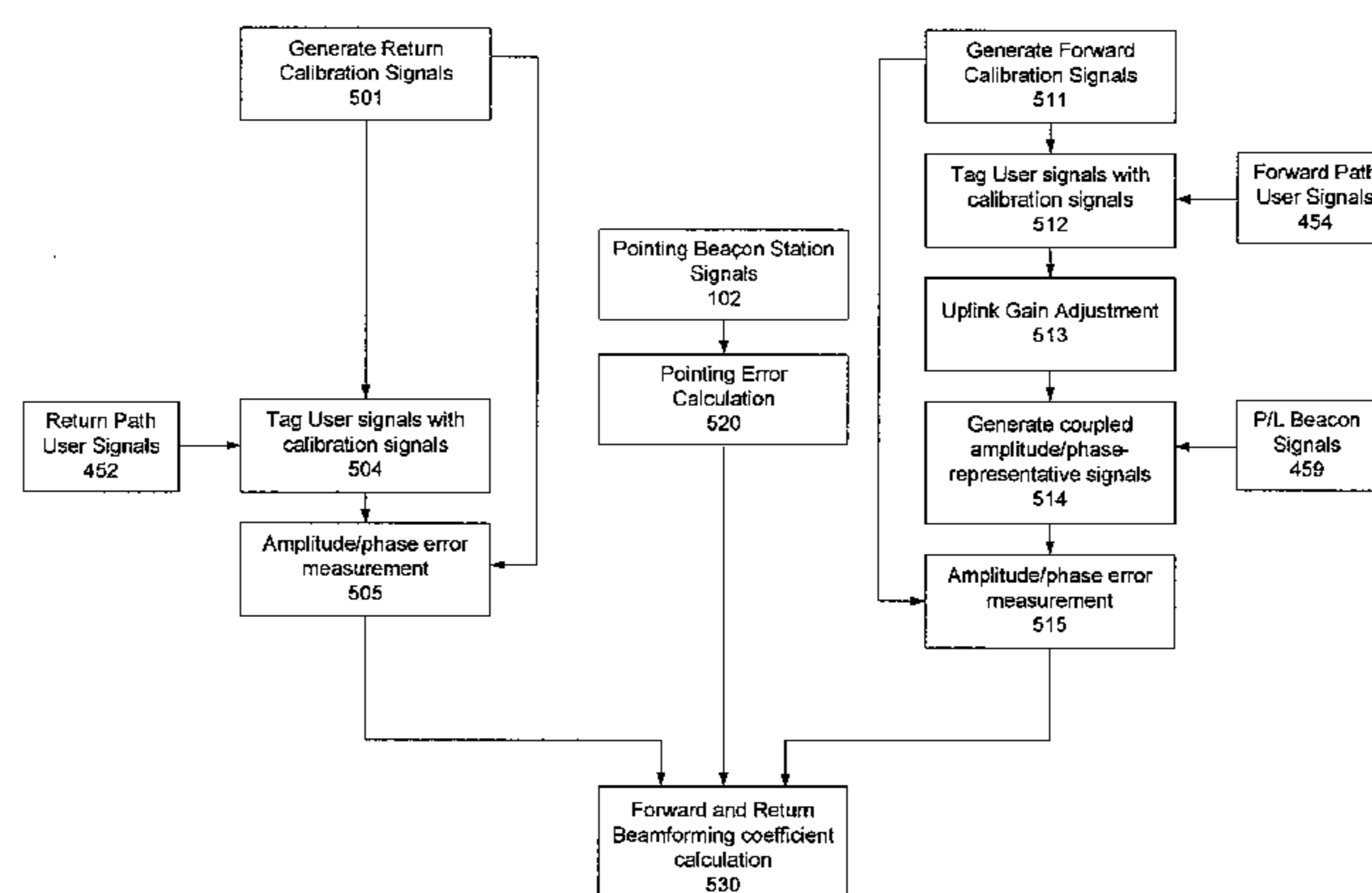
Methods, systems and apparatus for ground-based beam-
forming of a satellite communications payload (**200**) within a
satellite communications network (**100**). An embodiment of
the invention comprises a satellite (**11**) communicatively
coupled to at least one gateway (**12**) via a feeder link (**13**) and
further coupled to a plurality of user terminals (**16**), each
communicatively coupled with the satellite by a user link
(**17**). A ground based beam forming system (**400**) measures
and corrects amplitude and phase errors of a plurality of
return path signals (**452**) traveling from the user terminals
(**16**) via the satellite (**11**) to the at least one gateway (**12**), and
measures and corrects amplitude and phase errors of a plu-
rality of forward path signals (**457**) traveling from the at least
one gateway (**12**) via the satellite (**11**) to the user terminals
(**16**).

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18 Claims, 4 Drawing Sheets



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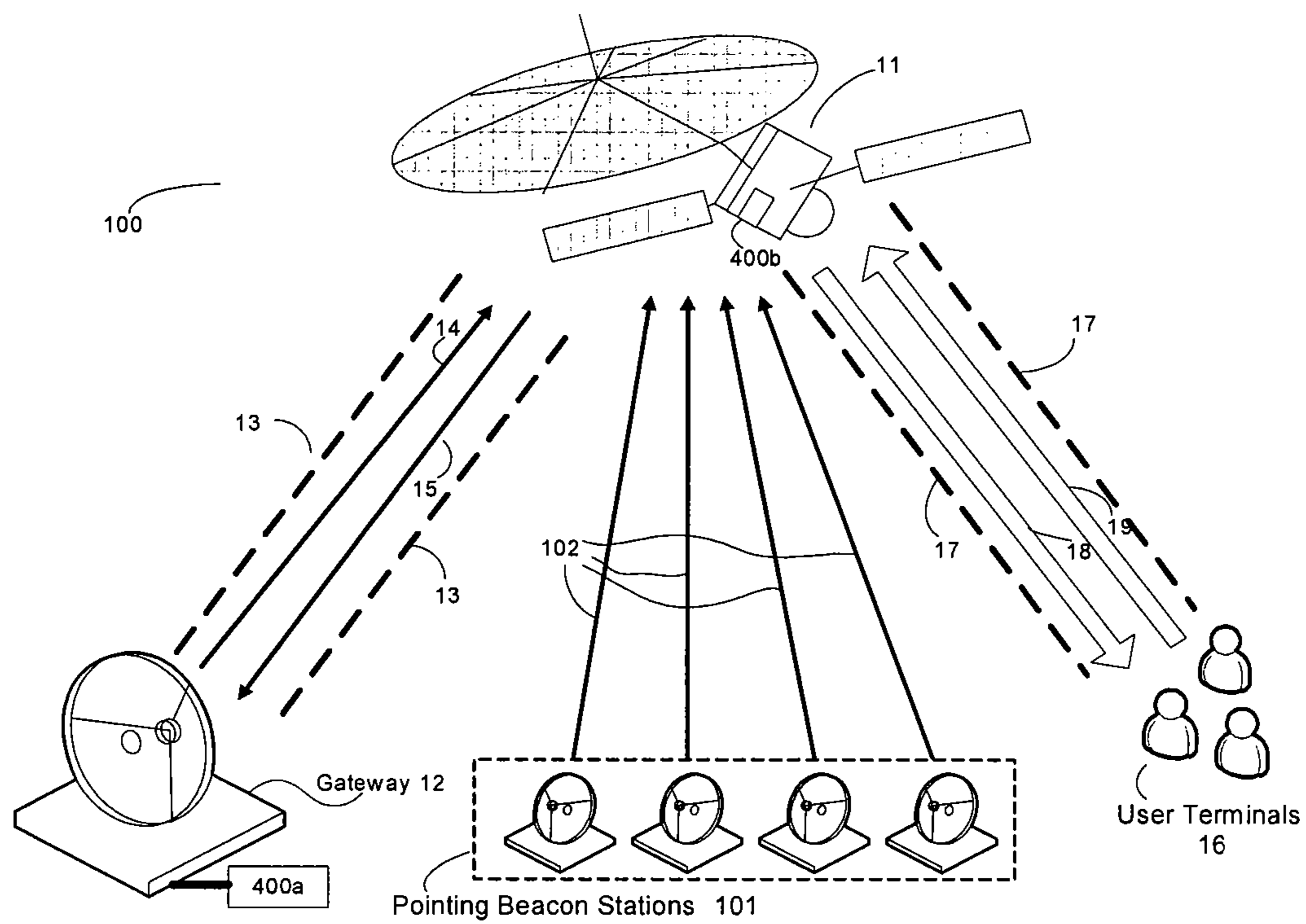


Figure 1

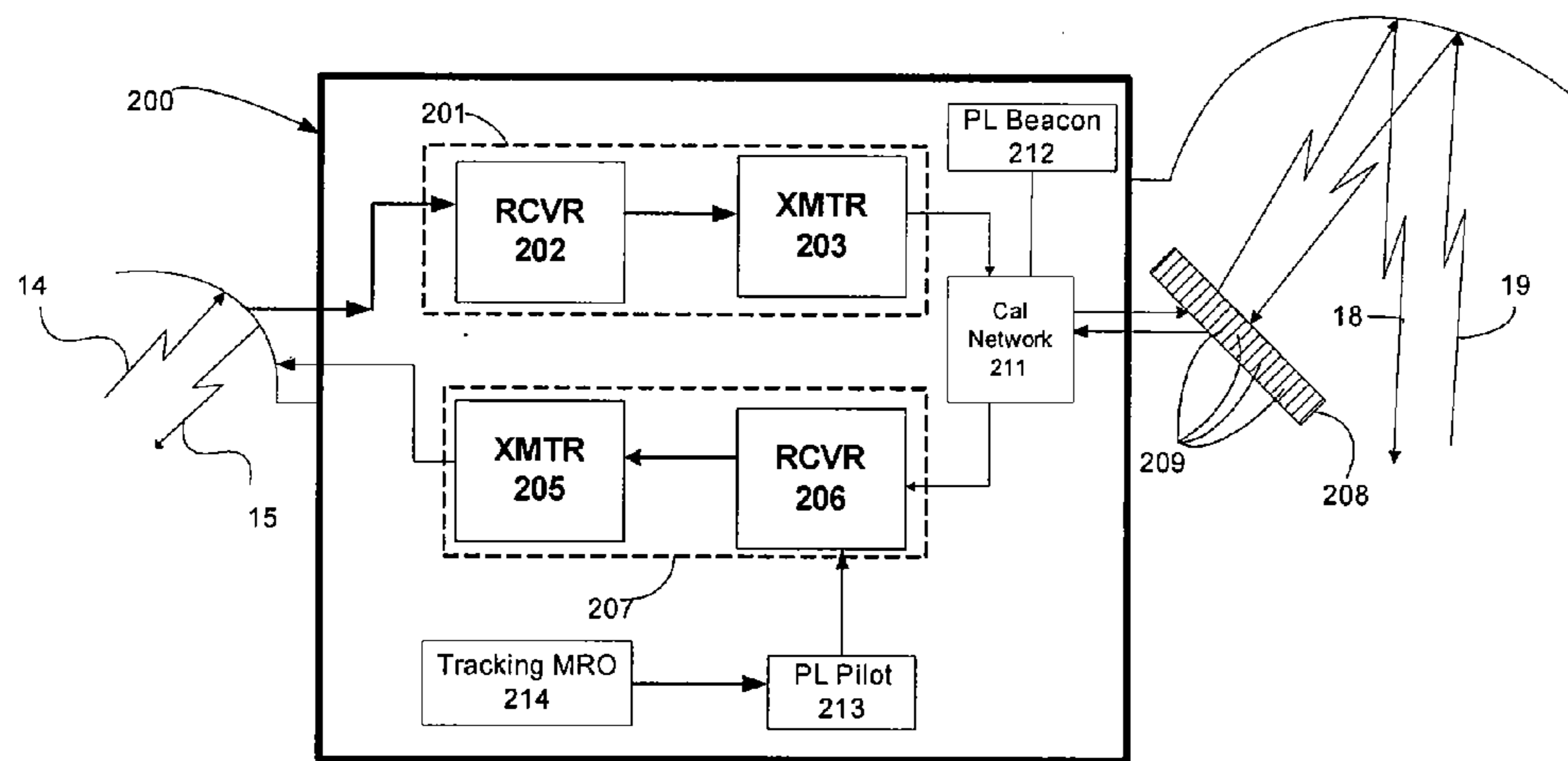


Figure 2

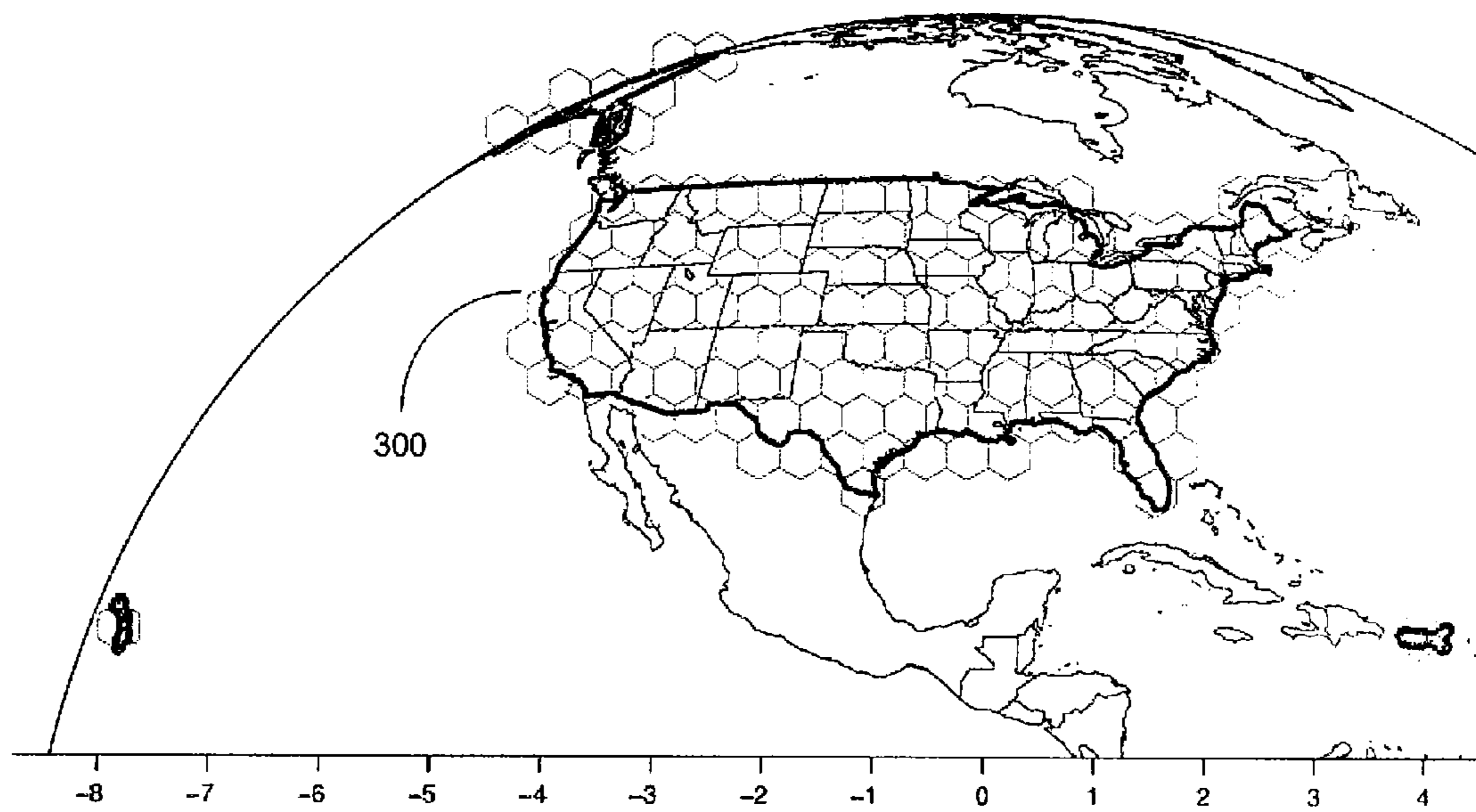


Figure 3

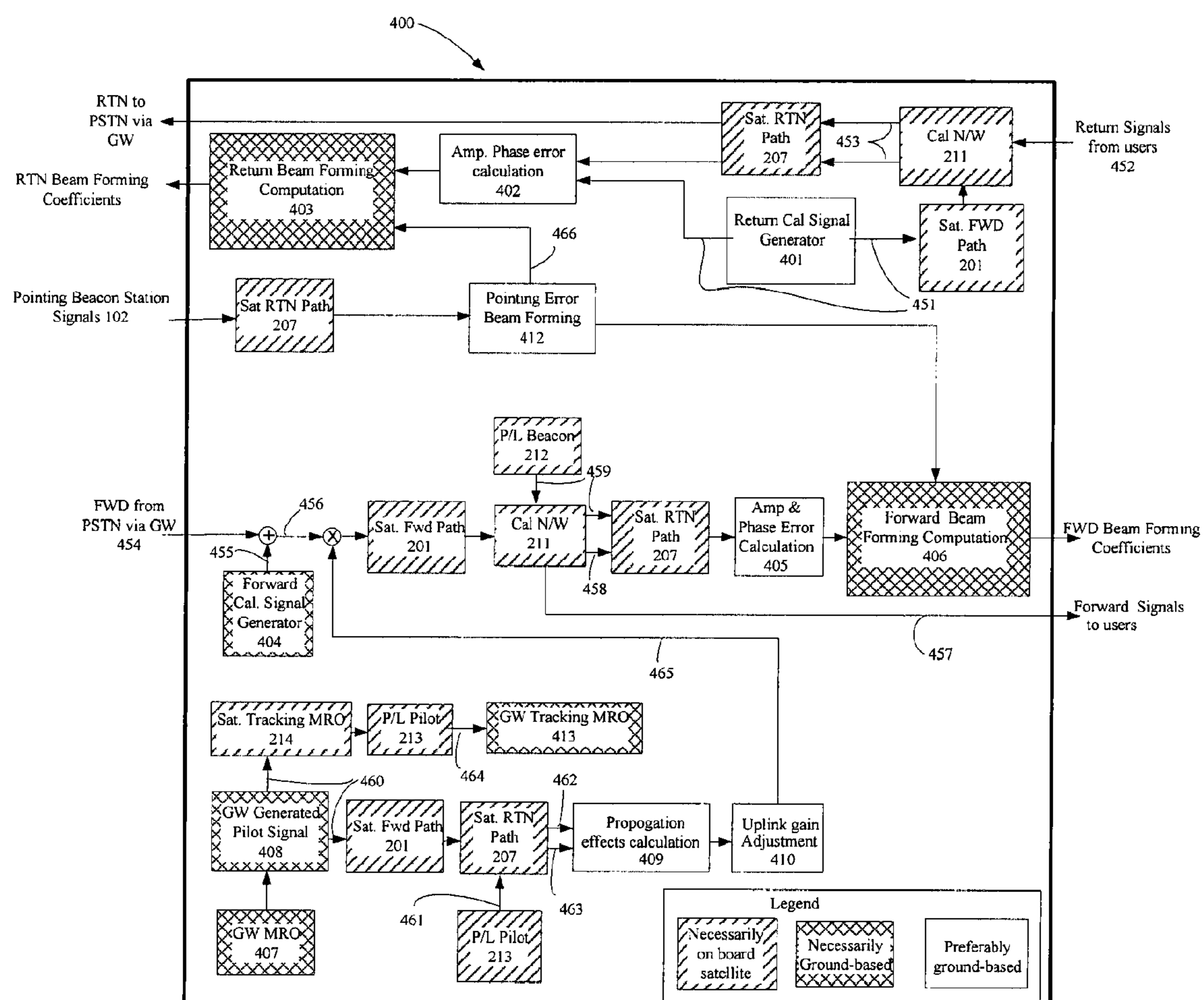


Figure 4

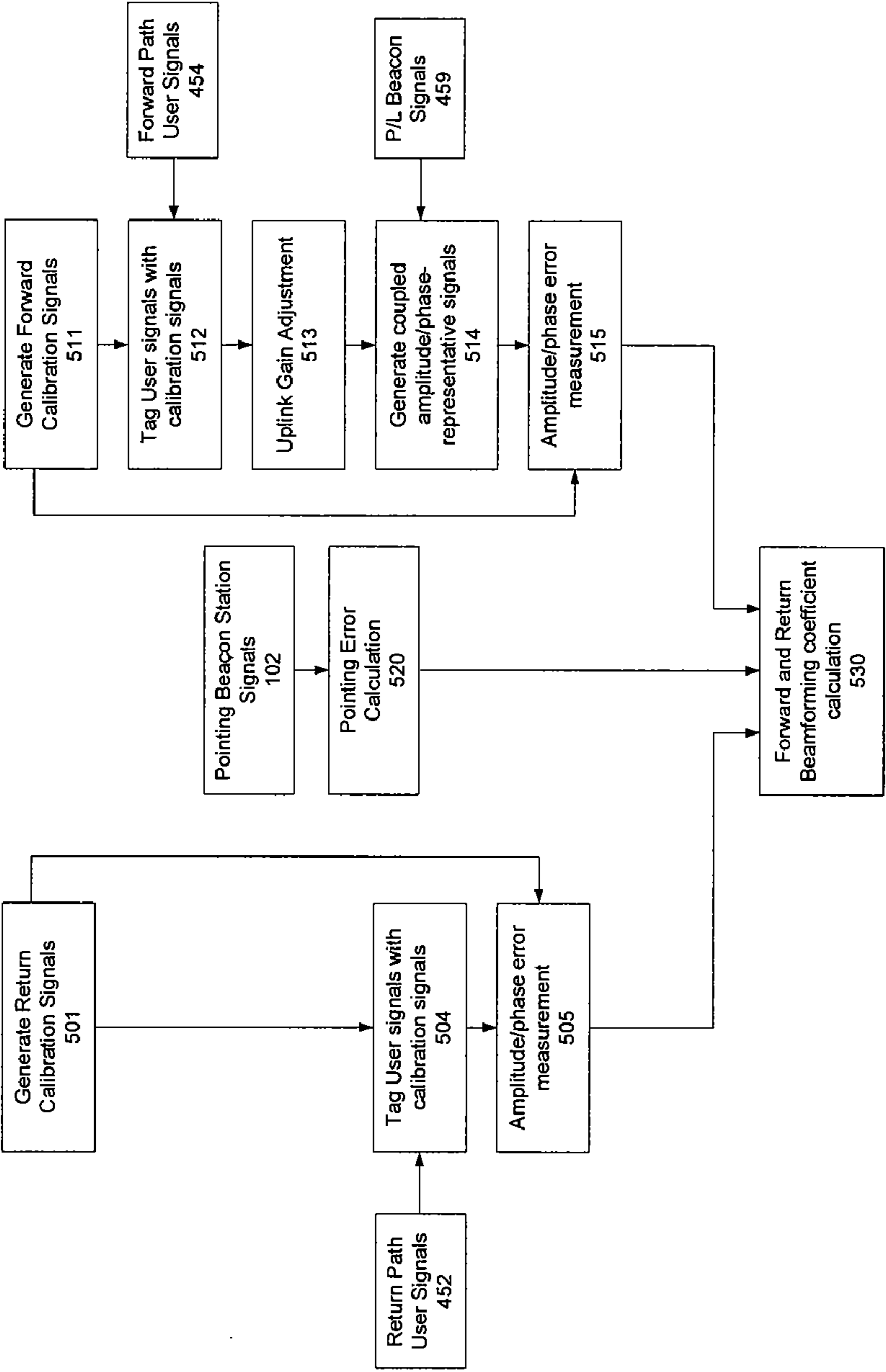


Figure 5

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**GROUND-BASED BEAMFORMING FOR
SATELLITE COMMUNICATIONS SYSTEMS**

TECHNICAL FIELD

This invention pertains to the field of satellite communications networks, and, in particular, to forming satellite beams from elementary feeds using largely ground-based apparatus and methods.

BACKGROUND ART

Many satellite communications systems require multiple beams to be placed over a geographic area. FIG. 3, for example, illustrates a pattern of coverage to provide service to the United States from a geostationary satellite located at 91 degrees west longitude. Numerous narrow beams may be formed from a relatively few elementary feeds by a process known as beamforming and described, for example, in U.S. Pat. Nos. 5,115,248 and 5,784,030. FIG. 3, for example, shows a pattern of 135 spot beams created from a feed array having only 48 elements. Adaptive beamforming permits electrical reconfiguration of the direction of each spot beam, or the formation of beams with different sizes and shapes, each accomplished without the need to change any hardware element.

A beamforming capability provides important benefits to many satellite payloads. For example, it permits a given satellite to operate from a number of different orbital locations. Thus, a satellite fleet operator licensed to operate geostationary spacecraft at multiple orbital locations may use a common hardware design for all locations and electrically configure the beam as required to tailor the spot beam pattern based on the satellite's location. Moreover, beamforming allows a satellite, which typically has a fifteen year life span, to be adapted on orbit to changing traffic patterns or new applications on the ground.

Beamforming, however, is technically challenging to perform on a satellite, inasmuch as the amplitude and phase relationship of each feed element within an array must be precisely set and provide for both the forward (gateway to satellite to user) signal path and the return (user to satellite to gateway) signal path. Conventional spacebased beamforming techniques include analog and digital beamforming networks (BFN's). Analog BFN's are generally co-located with the feed array, because it is otherwise difficult to compensate for losses or electrical path length variations between the feed apertures and the points of application of the beamforming coefficients. Volume and thermal constraints limit the number of analog BFN's that can be co-located with the feed array.

Digital BFN's have a better ability to compensate for losses or electrical path length variations between the feed apertures and the points of application of the beamforming coefficients. Accordingly, they can be employed in the middle of the payload at a considerable electrical path distance from the feed array, provided that strict attention is paid to design practices minimizing amplitude and phase variations and calibration processes that accurately track the variations.

The burdens associated with space-borne BFN's can be substantial, and include system reliability degradation, and added hardware mass, cost, power consumption and thermal control requirements. Moreover, if the BFN is on the satellite, the ability to introduce improved technologies and react flexibly to changing market demand is limited during the life of the satellite. Moving BFN functions to the ground is therefore desirable, but ground-based beamforming systems must overcome several additional problems not inherent in space-

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based beamforming. Among these are the need to compensate for gateway and satellite component performance changes over temperature and life, satellite and ground station pointing errors, and signal propagation amplitude and phase dispersion effects, including Doppler shifts.

These difficulties have limited the use of ground-based beamforming techniques. Known prior art techniques apply beamforming in only the return direction, or are limited to systems in which the feeder link signals are code division or time division multiplexed. Frequency division multiplexing is more commonly used in space, and offers significant cost and reliability advantages over code division and time division multiplexing.

The present invention provides for ground-based beamforming for both the forward and return communications path. The invention further provides for ground-based beamforming that can be employed in a system employing frequency division multiplexed signals.

DISCLOSURE OF INVENTION

Methods, systems and apparatus for ground-based beamforming of a satellite communications payload (200) within a satellite communications network (100). An embodiment of the invention comprises a satellite (11) communicatively coupled to at least one gateway (12) via a feeder link (13) and further coupled to a plurality of user terminals (16), each communicatively coupled with the satellite by a user link (17). A ground based beam forming system (400) measures and corrects amplitude and phase errors of a plurality of return path signals (452) traveling from the user terminals (16) via the satellite (11) to at least one gateway (12), and measures and corrects amplitude and phase errors of a plurality of forward path signals (457) traveling from the at least one gateway (12) via the satellite (11) to the user terminals (16).

BRIEF DESCRIPTION OF THE DRAWINGS

These and other more detailed and specific objects and features of the present invention are more fully disclosed in the following specification, reference being had to the accompanying drawings, in which:

FIG. 1 is a system level diagram of an exemplary satellite communications network.

FIG. 2 is a block diagram of a satellite communications payload operable within the satellite communications network of FIG. 1.

FIG. 3 illustrates an exemplary spot beam pattern suitable for the beamforming methods and apparatus of the present invention.

FIG. 4 is a block diagram of a ground-based beamforming system in accordance with the present invention.

FIG. 5 is a process flow diagram illustrating a method for ground-based beamforming in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED
EMBODIMENTS

Ground-based beamforming (GBBF) is most advantageous for missions that require spatial re-utilization of communication spectrum (bandwidth) over the satellite field of view (FOV), as exemplified by, but not limited to, Mobile Satellite Systems (MSS) providing communications services to personal, often hand-held, terminals. Accordingly, FIG. 1 illustrates a simplified diagram of an exemplary MSS system

100 to which a GBBF system is advantageously applied. The MSS system includes a satellite **11**, typically though not necessarily located at a geostationary orbital location defined by a longitude. Satellite **11** is communicatively coupled to at least one gateway **12** and to a plurality of user terminals **16**. The user terminals **16** comprise satellite terminals that may be handheld mobile telephones or car phones, or may be embedded in laptop or desktop personal computers, or phone booths. The at least one gateway **12** is coupled to the public switched telephone network.

Each gateway **12** and the satellite **11** communicate over a feeder link **13**, which has both a forward uplink **14** and a return downlink **15**. Each user terminal **16** and the satellite **11** communicate over a user link **17** that has both a forward downlink **18** and a return uplink **19**. Pointing beacon stations **101** are optionally employed to provide precise pointing feedback information to the GBBF system **400** as described hereinafter.

GBBF system **400** is a distributed control system having substantial elements **400a** on the ground, preferably co-located with one gateway **12**. These ground-based elements **400a** communicate with pointing beacon stations **101**, the co-located gateway **12**, and, via the corresponding feeder link **13**, with satellite **11**. Certain space-based elements **400b** of GBBF **400** are necessarily deployed on satellite **11**, as discussed hereinafter.

FIG. **2** is a simplified block diagram of a communications payload system **200** within satellite **11**. The communications payload system **200** has a satellite forward path **201** connecting forward uplink **14** to calibration network **211** by way of receiver **202** and transmitter **203**. Satellite forward path **201** also typically includes frequency converters, multiplexers, demultiplexers, amplifiers, filters, and other components known in the art but not shown in FIG. **2** for purposes of clarity. Communications payload system **200** also has a satellite return path **207** connecting calibration network **211** to return downlink **15** by way of receiver **206** and transmitter **205**. Again, many individual components known in the art are typically present in satellite return path **207** but have been omitted from FIG. **2** for purposes of clarity. Satellite forward path **201** and satellite return path **207** are communicatively coupled through calibration network **211** to forward downlink **18** and return uplink **19**, respectively, by way of feed array **208** which has multiple feed elements **209**.

As discussed in more detail hereinafter, four elements of GBBF **400** are integrated into satellite communications payload system **200**: calibration network **211**, payload beacon **212**, payload pilot **213**, and tracking master reference oscillator (MRO) **214**. Calibration network **211** includes low loss couplers that (a) permit user communications traffic to pass transparently in the forward and return directions and (b) simultaneously generate signals having the same amplitude and phase characteristics as the user traffic signals at each feed element **209**. These signals are passed to satellite return path **207** for transmission back to the at least one gateway **12**. Payload beacon **212** provides an encoded signal of known phase and amplitude to calibration network **211** for use in providing forward path signal amplitude and phase error correction, as discussed herebelow. Payload pilot **213** is a signal generator for use in providing Doppler frequency shift correction and forward uplink power control as discussed herebelow. Tracking MRO **214** is a tracking master reference oscillator for use in providing Doppler frequency shift correction, as discussed herebelow.

FIG. **3** is a pictorial representation of a beam pattern **300** that may be configured and controlled by the present inven-

tion. In the example shown in FIG. **3**, a pattern of **135** spot beams covers the continental United States, Hawaii, Alaska and Puerto Rico.

FIG. **4** is a block diagram of a GBBF system **400** in accordance with the present invention. As indicated in FIG. **4**, some space-based elements **400b** of GBBF system **400** are necessarily deployed on satellite **11**, others are necessarily disposed on the ground, and still others are preferably placed on the ground but may be deployed on satellite **11** without departing from the teachings of the present invention. The ground-based elements **400a** of GBBF system **400** are preferably co-located with any one gateway **12**.

Some elements of the GBBF system **400** are represented in FIG. **4** as computation or signal generating modules, which may be implemented in any combination of hardware, software and firmware. When implemented in software, the modules may be implemented in at least one computer readable medium, such as one or more hard disks, floppy disks, DVD's, CD's, etc.

The GBBF system **400** works cooperatively with certain standard conventional elements of the satellite communications network, for example, with satellite return path **207** and satellite forward path **201** of communications payload system **200**. In the preferred embodiment described herein, the spaceborne elements **400b** unique to GBBF system **400** are calibration network **201**, payload beacon **212**, payload pilot **213**, and tracking master reference oscillator (MRO) **214**.

GBBF system **400** constitutes a beamforming network that controls the overall shape of beam pattern **300** while in addition computing and applying beamforming coefficients that compensate for certain errors. Specifically, GBBF system **400** measures and corrects signal amplitude and phase errors associated with satellite return path **207**, return downlink **15**, forward uplink **14**, and satellite forward path **201**. Further, GBBF system **400** controls power of forward uplink **14**, minimizes errors associated with Doppler frequency shifts in links **13** and **17**, and corrects for satellite **11** pointing error. In a preferred embodiment, signals carried over each feeder link **13** are frequency domain multiplexed.

Return Path Signal Amplitude and Phase Error Correction.

An encoded return calibration signal **451** having a known amplitude and phase is generated at module **401** and transmitted to the satellite communications payload system **200** over each forward uplink **14**. Module **401** also provides the encoded return calibration signal **451** to amplitude and phase error calculation module **402**. In satellite **11**, the encoded return calibration signal **451** is processed through satellite forward path **201** to calibration network **211**. In calibration network **211**, return signals **452**, representing user communications traffic, are tagged with return calibration signal **451**. The tagged signals **453** are processed through the satellite return path **207**, and transmitted via return downlink **15** to amplitude and phase error calculation module **402**. Module **402** compares the amplitude and phase of the received, tagged signals **453** to the amplitude and phase of the calibration signal **451** generated at module **401**, the difference being representative of the amplitude and phase errors associated with satellite return path **207** and return downlink **15**.

The output of amplitude and phase error calculation module **402** is used in return beamforming computation module **403** together with the output of pointing error beamforming module **412** to update the beamforming coefficients, which are applied to return path user signals **452**.

Forward Path Signal Amplitude and Phase Error Correction

An encoded forward calibration signal **455**, having a known amplitude and phase, is generated by module **404**.

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User signals representing forward communications traffic **454**, typically originating in the PSTN and sent via gateway **12** are tagged with encoded forward calibration signal **455** and transmitted to satellite communications payload system **200** over forward uplink **14**. In satellite **11**, the tagged signals **456** are processed through satellite forward path **201**, converted to the user frequency band, and passed through calibration network **211**. Calibration network **211** outputs signals **457** representing user communications traffic to user terminals **16** via forward downlink **18**. Couplers disposed within calibration network **211** generate signals **458** having the same amplitude and phase characteristics at each feed element **209** as signals **457**. Encoded output **459** of payload beacon generator **212**, which is a signal having a known phase and amplitude, is passed, along with signals **458**, to amplitude and phase error calculation module **405** via satellite return path **207** and return downlink **15**.

In a preferred embodiment, amplitude and phase error calculation module **405** determines a difference between the known amplitude and phase of encoded forward calibration signal **455** and amplitude and phase characteristics of the output signals **458** of the calibration network couplers, as received on the ground through return downlink **15**. This difference is representative of an error associated with the signal's total path including the forward uplink **14**, satellite forward path **201**, satellite return path **207**, and return downlink **15**.

Amplitude and phase error calculation module **405** also determines a difference between the known amplitude and phase of encoded payload beacon signal **459** and the amplitude and phase characteristics of the payload beacon signal **459** as received at module **405**. This difference is representative of an error associated with the signal's complete return path, including the satellite return path **207** and return downlink **15**.

Finally, amplitude and phase error calculation module **405** determines the amplitude and phase error associated with the signal's complete forward path, including forward uplink **14** and satellite forward path **201**, by subtracting the difference representative of an error associated with the complete return path from the difference representative of an error associated with the total path.

The output of amplitude and phase error calculation module **405** is used in forward beamforming computation module **406** to update the beamforming coefficients, which are applied to forward path user signals **454**.

Forward Uplink Power Control

A gateway generated pilot signal **460** is generated by module **408** and transmitted over forward uplink **14** to satellite communications payload **200**, which passes gateway generated pilot signal **460** through satellite forward path **201**. Gateway generated pilot signal **460** together with a payload pilot signal **461** generated by payload pilot module **213** is passed over satellite return path **207** to feeder link transmitter **205**, which transmits transponded gateway generated pilot signal **462** and payload pilot signal **461** over return downlink **15**. Propagation effects calculation module **409** determines the propagation effect associated with forward uplink **14**, by comparing the signal level of the received payload pilot signal **463** to the signal level of transponded gateway generated pilot signal **462**. This propagation effect is compensated for by uplink gain adjustment module **410**, which provides a control signal **465** that adjusts the power level of forward uplink **14**.

Doppler Frequency Shift Error Minimization

Although for many purposes, geostationary satellites may be considered motionless with respect to any point on the ground, they are nevertheless subject to drift velocities that

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produce noticeable Doppler frequency shifts that can prevent accurate ground-based beamforming. In accordance with a preferred embodiment of the present invention, errors associated with Doppler frequency shifts are minimized in the following manner. Gateway generated pilot signal **408** is locked to gateway master reference oscillator **407** and transmitted over forward uplink **14** to satellite communications payload **200**, where it is applied to satellite tracking master reference oscillator **214**. Satellite tracking master reference oscillator **214** is locked to payload pilot signal **213**. Payload pilot signal **213** is transmitted over return downlink **15** to gateway tracking master reference oscillator **413**, which is locked to the received payload pilot signal **464**. All frequency conversions on the ground are locked to the gateway master reference oscillator **407** in the forward path direction, and locked to the gateway tracking master reference oscillator **413** in the return path direction. All frequency conversions on the satellite are locked to the satellite tracking master reference oscillator **214**.

Satellite Pointing Error Correction.

Signals **102** generated by a plurality of pointing beacon stations **101** operating at known locations in the user frequency band are received by satellite **11** over uplinks operating at the same frequency as return uplink **19**, passed through satellite return path **207**, and transmitted to the ground over return downlink **15**. Pointing error beamforming module **412** calculates and generates pointing error correction coefficients **466** to compensate for the error between the measured beam pointing direction and the desired beam pointing direction. Coefficients **466** are provided to forward and return beamforming computation modules **406** and **403**, respectively.

The operation of the GBBF system **400** will now be discussed relative to the flow diagram shown in FIG. 5. At block **501**, return calibration signal **451** having known amplitude and phase is generated by module **401** and passed through the satellite forward path **201** to the calibration network **211** which also receives ordinary return signals from users **452**. At block **504**, the user signals **452** are tagged with return calibration signal **451**, by calibration network **211** and the tagged signals passed, through the satellite return path **207** to block **505**. Amplitude and phase errors are measured at block **505** by module **402** which compares the known amplitude and phase of signals **451** with the amplitude and phase of signals received from block **504**. The errors measured at block **505** are input to beam forming coefficient calculation, block **530**.

At block **511**, forward calibration signal **455** is generated by module **404**. At block **512** ordinary forward path user signals **454** are tagged with the forward calibration signal **455**. The tagged signals **456** are gain adjusted at block **513** by module **410**, and passed through satellite forward path **201** to calibration network **211**. Calibration network **211** also receives encoded payload beacon signals **459** having a known gain and amplitude from payload beacon generator **212**. At block **514**, amplitude and phase characteristics **458** of tagged user signals **456** are output by calibration network **211** along with payload beacon signals **459**. Signals **458** and **459** are passed through the satellite return path **207** to block **515**. Amplitude and phase errors are measured at block **515** by module **405** which compares the known amplitude and phase of signals **455** and **459** with the amplitude and phase of signals received from block **514**. The errors measured at block **515** are input to beam forming coefficient calculation, block **530**.

Pointing error calculation **520** receives pointing beacon station signals **102** and outputs a pointing error estimation to beam forming coefficient calculation, block **530**.

At block 530, beamforming coefficients are calculated by modules 403 and 406 for the return and forward paths, respectively.

The above description is included to illustrate the operation of the preferred embodiments and is not meant to limit the scope of the invention. The scope of the invention is to be limited only by the following claims. From the above discussion, many variations will be apparent to one skilled in the art that would yet be encompassed by the spirit and scope of the present invention.

What is claimed is:

1. A satellite communications network having a ground-based beamforming (GBBF) system, said network comprising:

a satellite, said satellite comprising a satellite communications payload, said satellite communications payload comprising a satellite return path and a satellite forward path, a satellite tracking master reference oscillator, a calibration network, a plurality of couplers, a satellite generated payload beacon signal, a satellite generated payload pilot signal, and a plurality of multipart amplifiers coupled to a plurality of hybrid matrixes;

at least one gateway, communicatively coupled with the satellite via a feeder link;

a plurality of user terminals, each communicatively coupled with the satellite by a user link; and

a plurality of pointing beacon stations adapted to transmit and receive signals to and from the satellite;

wherein the GBBF system:

comprises a plurality of hybrid matrix outputs corresponding to a plurality of feed elements, a gateway generated pilot signal, a master reference oscillator, and a gateway tracking master reference oscillator;

measures a first set of amplitude and phase errors of a plurality of return path signals traveling from the user terminals via the satellite to the at least one gateway by:

generating an encoded return calibration signal having a known amplitude and phase that is received by the satellite communications payload and applied to each of a plurality of feed elements in a feed array;

receiving, from the calibration network over the satellite return path and a return downlink between the satellite and the gateway, a plurality of tagged signals, each of the plurality of tagged signals comprising a combination of user communications traffic and the encoded return calibration signal; and

determining a difference between the known amplitude and phase of the encoded return calibration signal and an amplitude and a phase of each of the plurality of tagged signals, the difference being representative of said first set of amplitude and phase errors;

corrects said first set of amplitude and phase errors by generating, on the ground, a first set of corrective beam forming coefficients, and applying said first set of corrective beam forming coefficients to said return path signals to minimize the amplitude and phase errors of the plurality of return path signals;

measures a second set of amplitude and phase errors of a plurality of forward path signals traveling from the at least one gateway via the satellite to the user terminals; and

corrects said second set of amplitude and phase errors by generating, on the ground, a second set of corrective

beam forming coefficients, and applying said second set of corrective beam forming coefficients to said forward path signals.

2. The satellite communications network of claim 1 wherein the forward path signals are frequency division multiplexed.

3. The satellite communications network of claim 1 wherein the return path signals are frequency division multiplexed.

4. The satellite communications network of claim 1 wherein the GBBF system forms beams using a plurality of feed elements in a forward downlink from the satellite to the user terminals and in a return uplink from the user terminals to the satellite.

5. The satellite communications network of claim 1 wherein the GBBF system controls power of a forward uplink from the at least one gateway to the satellite.

6. The satellite communications network of claim 1 wherein the GBBF system minimizes errors associated with Doppler frequency shifts.

7. The satellite communications network of claim 1 wherein the GBBF system corrects for satellite pointing errors.

8. The satellite communications network of claim 1, wherein the encoded return calibration signal is applied to each of the plurality of feed elements in the feed array through the calibration network.

9. The satellite communications network of claim 1, wherein the encoded return calibration signal is applied to each of the plurality of feed elements in the feed array via a calibration horn.

10. The satellite communications network of claim 1, wherein the encoded return calibration signal is encoded by means of a Walsh function and pseudo random number scrambling.

11. The satellite communications network of claim 1, wherein the encoded return calibration signal is generated on-board the satellite.

12. The satellite communications network of claim 1 wherein the GBBF system measures and corrects amplitude and phase errors of the plurality of forward path signals by:

generating an encoded forward calibration signal having a known amplitude and phase and a plurality of tagged signals, each of the plurality of tagged signals comprising a combination of user communications traffic and the encoded forward calibration signal;

transmitting the plurality of tagged signals over a forward uplink to the communications payload, which passes the plurality of tagged signals through the satellite forward path and through the calibration network, which passes the plurality of tagged signals to a forward downlink, and passes amplitude and phase characteristics of the plurality of tagged signals through the satellite return path together with an inserted payload beacon signal having a known amplitude and phase;

receiving over a return downlink amplitude and phase characteristics of each of the plurality of tagged signals and a received payload beacon signal;

determining a difference between the known amplitude and phase of the encoded forward calibration signal and amplitude and phase characteristics of each of the plurality of tagged signals, which difference is representative of an error associated with a total path consisting of the forward uplink, the satellite forward path, the satellite return path and the return downlink;

determining a difference between the known amplitude and phase of the inserted payload beacon signal and an

amplitude and phase of the received payload beacon signal, which difference is representative of an error associated with a complete return path, the complete return path consisting of the satellite return path and the return downlink;

subtracting the difference representative of the error associated with the complete return path from the difference representative of the error associated with the total path to obtain an error representative of a complete forward path, the complete forward path consisting of the forward uplink and the satellite forward path; and

generating and applying corrective beamforming coefficients and hybrid matrix correction factors to minimize amplitude and phase errors of the plurality of forward path signals.

13. The satellite communications network of claim 1 wherein the GBBF system controls power of a forward uplink by:

transmitting the gateway generated pilot signal over the forward uplink to the satellite communications payload, which passes the gateway generated pilot signal through the satellite forward path, passes the gateway generated pilot signal together with the satellite generated payload pilot signal over the satellite return path to a feeder link transmitter, and transmits a transponded gateway generated pilot signal and the satellite generated payload pilot signal to the at least one gateway over a return downlink;

receiving the transponded gateway generated pilot signal and a received payload pilot signal from the return downlink;

determining a propagation effect associated with the forward uplink by comparing a signal level of the received payload pilot signal to a signal level of the transponded gateway generated pilot signal; and

providing a control signal that adjusts a power level of the forward uplink to compensate for the propagation effect.

14. The satellite communications network of claim 1 wherein Doppler frequency shift errors are minimized by:

locking the gateway generated pilot signal to the master reference oscillator; transmitting the gateway generated pilot signal over a forward uplink to the satellite communications payload;

applying the gateway generated pilot signal to the satellite tracking master reference oscillator;

locking the satellite tracking master reference oscillator to the satellite generated payload pilot signal;

transmitting the satellite generated payload pilot signal over a return downlink to the at least one gateway;

receiving the satellite generated payload pilot signal at the at least one gateway; and

locking the gateway tracking master reference oscillator to the satellite generated payload pilot signal.

15. The satellite communications network of claim 1 wherein satellite pointing errors are corrected by:

receiving pointing beacon signals generated by the plurality of pointing beacon stations operating at known locations over a return uplink;

transmitting the pointing beacon signals over a return downlink; and

calculating and compensating for errors between measured beam pointing direction and desired beam pointing direction.

16. A method for ground-based beamforming (GBBF) of a communications payload on a satellite, said payload comprising a calibration network, a satellite return path, said method comprising:

measuring a first set of amplitude and phase errors of a plurality of a plurality of return path signals traveling from user terminals via the communications satellite payload to at least one gateway by:

generating an encoded return calibration signal having a known amplitude and phase that is received by the satellite communications payload and applied to each of a plurality of feed elements in a feed array;

receiving from the calibration network over the satellite return path and a return downlink between the satellite and the gateway a plurality of tagged signals, each of the plurality of tagged signals comprising a combination of user communications traffic and the encoded return calibration signal; and

determining a difference between the known amplitude and phase of the encoded return calibration signal and an amplitude and a phase of each of the plurality of tagged signals, the difference being representative of said first set of amplitude and phase errors;

correcting said first set of amplitude and phase errors by generating, on the ground, a first set of corrective beam forming coefficients, and applying said first set of corrective beam forming coefficients to said return path signals to minimize the amplitude and phase errors of the plurality of return path signals;

measuring a second set of amplitude and phase errors of a plurality of forward path signals traveling from the at least one gateway via the satellite to the user terminals; and

correcting said second set of amplitude and phase errors by generating, on the ground, a second set of corrective beam forming coefficients, and applying said second set of corrective beam forming coefficients to said forward path signals.

17. The method of claim 16 further comprising:

controlling a plurality of feed elements to form desired beam shapes in a forward downlink from the satellite to the user terminals and in a return uplink from the user terminals to the satellite.

18. The method of claim 17, wherein, at least one of the forward and return path signals are frequency division multiplexed.